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ON THE CONDITIONS UNDER WHICH THE VEGETABLE MATTER OF THE ILLINOIS COAL BEDS ACCUMULATED

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All students of the subject agree that coal was derived from vegetable material which has undergone imperfect decomposition without free access of air. The complete explanation of the coal beds involves, among other things, an explanation of (1) the method and conditions under which the plant material accumulated; (2) the kinds and proportions of the different plants that contributed the vegetable material; and (3) the chemical changes by which the plant tissues were transformed into coal. The first part of the problem, with regard to the method and the conditions under which the vegetable matter of the coal beds accumulated, can be studied somewhat independently of the other two, and the solution should be found in the structural features of the coal beds and associated strata.

Two important theories have been proposed to explain the mode of accumulation of the vegetable matter of coal beds. The older of these, known as the "transport or driftage theory," assumes that the vegetable materials grew on land areas, whence they were carried by streams and deposited in the bodies of water where they accumulated. The other, known as the "swamp or growth-in-place theory," was suggested in 1778, and assumes that the vegetable matter of coal beds accumulated in swamps practically in the places where the plants grew.

The following facts presented in the principal coal beds of Illinois make impossible the application of any form of the transport theory of accumulation of the vegetable material: (1) the great extent of the coals—the Herrin (No. 6) and Springfield (No. 5) beds extend in practical continuity over at least 7,000 square miles, and probably over a considerably greater area in the state; (2) the regularity of thickness of the coals—the Herrin (No. 6) bed ranges from 7 to 9 feet over a known area of at least 5,000 square miles. A thin band of shale or shaly coal ("blue band"), one-half to two inches thick, is present 18–24 inches above the floor of this coal over practically the entire area of its distribution, and the thickness of the benches above and below the "blue band" is remarkably uniform. The Springfield (No. 5) bed, also, scarcely varies one foot in thickness over more than 5,000 square miles; (3) the small percentage of mineral matter or ash in the coal shows that very little mud and sand sediments were mixed with the plant remains as they accumulated.

In times of flood the amount of mud and sand carried by streams is so great compared with the amount of vegetable matter, and the latter is deposited so irregularly, that it can scarcely be imagined how the plant material of these coal beds could have been carried by streams into the Illinois basin, and have accumulated in practical continuity over such extensive areas, in anything like such uniform thickness, and with so little mingling of mineral sediments. Extensive areas of relatively pure vegetable matter are known to be accumulating in swamps at the present time, but there is no known place where plant remains transported by streams during floods are accumulating as a continuous bed over any considerable area in anything approaching regularity of thickness and without a very large mixture of sand and mud; nor does it seem probable that pure transported vegetable deposits have ever accumulated over any considerable area in the past.

From a study of the small coal basins of France in recent years Fayol, supported by De Lapparent and other French geologists, has revived the transport theory of accumulation of the vegetable matter of coal beds. However, practically every geologist who has studied extensive coal beds, especially those of the Appalachian region of the United States, with which the coal beds of Illinois are comparable, has rejected the transport theory of accumulation as applied to those beds. Rogers Brothers, Lesquereux, Dawson, Andrews, Dana, Orton, Stevenson, White, and Ashley have all accepted the growth-in-place theory of accumulation of the vegetable matter of extensive coal beds as the only one that is consistent with the facts. It seems safe to assume, then, that the vegetable matter of the coal beds of Illinois accumulated practically in the places where the plants grew.

The acceptance of the growth-in-place theory of accumulation does not settle the question whether the basins bordered the sea, as lagoons, or occupied broad depressions over coastal plains, as the Dismal Swamp, or covered large areas over river flood plains; nor is it purposed to discuss this phase of the question at this time. The fact that the vegetable matter of coal beds accumulated under water in the places where the plants grew does not prove that the water was ever more than a few inches, or at most a very few feet, in depth, even where coal beds 5–10 feet thick have been formed. On the contrary, the structural features of the coal beds indicate conclusively that the water in which the vegetable matter accumulated was very shallow as well as that it was very quiet.

STRUCTURAL FEATURES OF THE COAL BEDS

One of the more conspicuous structural features of the coal beds of Illinois, which are representative of the larger beds everywhere, is their stratification, the more prominent bedding planes being 3–5 or more inches apart. These bedding planes form partings along which the coal separates rather easily, and they usually show well-developed bands of "mother coal" or mineral charcoal. These stratification planes often become more conspicuous when the bed is weathered, but some of them are prominent on unweathered faces. Such a conspicuous clean parting of mineral charcoal occurs 20–24 inches below the roof of the Herrin coal over several hundred square miles in western and southern Illinois, and appears to be almost coextensive with that bed. Along this charcoal zone the coal separates so perfectly that where the overlying shale does not stand well in the mines the bench above this parting is left for a roof. Five or six inches higher is another mineral charcoal parting almost equally well developed and persistent.

Between the more prominent partings and bedding planes the coal from roof to floor is made up of alternating bright and dull laminae, which are usually $\frac{1}{2}$ to $\frac{1}{32}$ of an inch thick, though in places they are considerably thicker. The aggregate dull bands generally make up nearly or quite one-half of the coal beds, and they appear to be of the same general nature as the bedding planes mentioned above. They are often rather uniform in thickness over considerable areas, but in places they thicken for some distance and in others they thin down to knife-edge partings. The bright laminae appear to be rather homogeneous in structure; but where the coal is split along well-developed dull laminae the cleavage planes almost always show distinct mineral charcoal surfaces. A typical dull lamina appears to be composed of a film of dull, structureless coal at the top, which passes downward into coarse-textured, fibrous, mineral charcoal in the middle part, and this, in turn, grades downward into a film of dull, structureless coal below.

The features above described are not peculiar to Illinois coals. H. S. Rogers and others have noted the alternations of laminae of bright and dull coal, and the predominance of mineral charcoal in the dull laminae, in the coals of the Appalachian region, and the writer has observed the same characteristics in the coals of Iowa. They have been described from coal beds generally in different parts of the world. The mineral charcoal is so constantly present, and so intimately mingled in, and constitutes such an important part of, the dull laminae of the coals of Illinois that they must have been developed together, and a satisfactory explanation of the one must also explain the other.

THE "MOTHER COAL" OR MINERAL CHARCOAL

Two main explanations have been proposed to account for the origin of mineral charcoal. One of these, held by many paleobotanists and chemists in recent times, explains the mineral charcoal as formed from charred plant tissues resulting from forest fires sweeping over land areas, the charred fragments being subsequently swept by flooded streams into the basins, where they were deposited with the mass of vegetable matter there in process of accumulation.

This explanation assumes that a considerable part of the vegetable matter of the coal was transported material, which assumption is open to all of the objections to the transport theory mentioned above. It assumes that a very important proportion of the coal was derived from plant tissues that had been charred by fires previous to their accumulation, and that these charred fragments had been carried into the coal basin by streams in such enormous quantities as to cover the surface of practically the entire area of the present coal beds, 5,000–8,000 square miles or more in extent; that this process took place not only once but was repeated as many times as there are persistent dull, charcoal-bearing laminae, requiring scores of recurrences of such charcoal deposition during the accumulation of the vegetable matter of each of the large coal beds. It assumes such a depth of water above the accumulating vegetable matter that the charred fragments brought in by the streams could be freely floated out above the mass of vegetable matter already present to every part of the basin, and, most impossible of all, that the streams that carried such vast quantities of charred vegetable matter carried little or no mud or mineral sediments. If it is assumed that the water of the basin was so shallow that the clay and sand brought down by the streams were strained out in the meshes of the tangled plant débris at the margin, then the same vegetable sieve would catch the charred plant fragments and not permit them to be distributed to every part of the accumulating coal beds. This explanation is not in harmony with the facts of the vertical and horizontal distribution of the mineral charcoal bands in the coal beds.

The modification of this view assumes that the mineral charcoal represents partially burned vegetable matter resulting from fires sweeping over the surface of the marshes in which the vegetable matter of the coal beds was accumulating. It is not probable that fires started by lightning would travel over water-covered swamps with only the living undergrowth and green leaves and branches of the trees to support the flames, and if they did, they would not leave such uniform and thick layers of charcoal as occur in well-developed dull laminae. If it is assumed that the surface of the vegetable matter that had accumulated in the swamp had been exposed and dried before the fires swept over it, then the conditions involved would be similar to those under which the charcoal is interpreted as having been formed by the partial atmospheric decay of the upper surface of the vegetable material of the bog exposed during periods of unusual low water.

It seems to the writer that the explanation of mineral charcoal as resulting from the temporary exposure and partial atmospheric decay of the surface portion of the vegetable matter in the bog, instead of the assumption that it must have been charred by fire, is much more consistent with the following facts: (1) the frequent repetitions of the dull laminae containing such large amounts of mineral charcoal; (2) the larger number of plant spores in the dull laminae than in the bright coal; (3) the numerous pinnae and pinnules of ferns[1] in the midst of the mineral charcoal fragments; (4) the absence of layers of ash that would result from the burning of the vegetable matter at the surface of the bog; and (5) the changes that take place in the vegetable matter at the surface of shallow marshes during periods of drought and exposure at the present time.

EXPLANATION OF THE BRIGHT AND DULL LAMINAE

In explaining the origin of the bright and dull laminae, Dawson[2] maintained that it is the outer bark of flattened tree trunks that alone formed the shining coal. In a recent paper on the origin of bright laminae of coal, Pringle,[3] of the Geological Survey of Great Britain, reaffirms Dawson's view.

The serious objection to this view is the fact that the bright and dull laminae of the coal beds are so nearly parallel and are often continuous for long distances. Trees that are overturned in swamps fall in various directions, and their trunks lie across one another at different angles. If the cortical portion of tree trunks formed the bright laminae of coal, these bright laminae would not be continuous for long distances, and the dull laminae would be broken at short intervals by small areas of bright coal representing the cross-sections and oblique sections of the cortical portions of tree trunks that lay at different angles and at different levels from those that formed the bright bands in any exposure. The distribution of the bright and dull laminae is not consistent with this explanation.

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[1] David White, *Econ. Geol.*, III (1908), 302.

[2] J. W. Dawson, "On the Conditions of the Deposition of Coal," *Quar. Jour. Geol. Soc.*, XXII (1866), 141.

[3] John Pringle, "On the Origin of Bright Laminae of Coal," *Trans. Edin. Geol. Soc.*, X, Pt. 1 (1912), 33.

Microscopic examination of bituminous coal has shown that spores are more numerous in the dull laminae than in the bright, and hence some geologists have concluded that the dull laminae resulted from the greater number of spores in these bands, while the bright laminae were formed from the more woody portions of the plants. However, a study of the dull laminae shows that, while they may contain spores in greater abundance than the bright laminae, yet they are very largely composed of mineral charcoal, which certainly has been derived from plant tissues other than spores.

The alternation and great extent of the bright and dull laminae are such constant features of the coal beds, and the mineral charcoal is so generally present in the dull laminae, that any adequate explanation of the origin of these features must involve agencies that were repeatedly operative over practically the entire area of accumulation of the coal beds. The only recurrent agency of such widespread action is change in the water level of the basin during the time the vegetable material was accumulating.

If it is assumed that the dull laminae resulted from the flooding of the basin, we should have associated with the dull laminae bands of mud deposited during such times of flood. We are not left to speculate with regard to the effects of flooding of the basin during the progress of accumulation of the vegetable matter of the coal, for we have such an example in the clay band or "blue band" of the Herrin (No. 6) coal, which extends over practically the entire area of its distribution, and is clearly a mud parting due to flooding. Black shale partings, common in portions of some coal beds, as in coal No. 1, are also records of flooding of the coal-forming marshes. The typical dull laminae and mineral-charcoal zones in the large coal beds of Illinois, as elsewhere, are not such mud partings. They usually contain only a slightly, if any, greater percentage of ash than the bright bands and are practically free from clay silt. They contain a relatively smaller percentage of volatile matter and a larger proportion of fixed carbon than the bright bands. A number of proximate analyses of mineral charcoal compared with those of average coals from the same beds are given in Table I. It will be seen from this table of analyses that the mineral charcoal generally contains but little, if any, more ash than the average coal of the bed in which it occurs.

TABLE I

PROXIMATE ANALYSES OF MINERAL CHARCOAL AND AVERAGE COALS FROM THE SAME SEAMS

(*a*) Charcoal Samples; (*b*) Average Samples

	Water	Volatile Matter	Fixed Carbon	Ash	Ash in Charcoal above or below That in Average Sample
1*a*	1.17	19.77	72.13	6.93	+4.69
1*b*	1.94	39.26	55.83	2.24	
2*a*	.75	20.36	71.07	7.82	+3.04
2*b*	1.37	37.80	54.46	4.78	
3*a*	2.39	12.40	75.34	9.87	+4.20
3*b*	1.68	34.97	57.00	5.67	
4*a*	.52	14.32	64.03	21.13	+3.92
4*b*	1.04	28.01	49.24	17.21	
5*a*	.55	9.92	81.37	8.16	−1.97
5*b*	.85	16.85	69.58	10.13	
6*a*	.85	88.36	87.64	3.15	−2.18
6*b*	1.19	20.76	71.70	5.33	
7*a*	.57	20.98	70.37	8.08	−2.52
7*b*	.77	17.11	70.74	10.60	
8*a*	.85	10.49	84.01	4.65	−3.74
8*b*	.94	17.85	72.15	8.39	
9*a*	1.58	23.96	64.28	10.18	− .54
9*b*	2.33	34.91	52.03	10.72	

Nos. 1–8, analyses by McCreath, *Second Geological Survey of Pennsylvania*, Vol. MM, pp. 1–107; moisture at 225 degrees F.

No. 9, analyses Illinois Geological Survey, Herrin (No. 6) coal, Williamson County, Illinois; moisture air-dried.

After discussing the original amount and the composition of the ash contained in living species of such types of coal plants as lycopods, ferns, and equiseta, Stevenson[1] concludes that "one should expect to find in ordinary [pure] coal not much less than 6 per cent of ash, or even more, in which silica and alumina should predominate greatly." He thinks it probable that coals containing less inorganic matter than the plant substance should have yielded have had some of the original inorganic content removed in solution. It is also probable that some coals which locally contain more than the original amount of inorganic content, as pyrites lenses, etc., have been situated in places favorable for deposition of minerals rather than solution, and in this way have become enriched in their mineral content. It is also probable that in many places a small percentage of the inorganic constituents of the coal, above that originally present in the plants, may have come from wind-blown dust that settled over the coal basin during the long period of accumulation of the vegetable matter. The amount of ash in a coal bed varies very considerably at different levels and in different places even in the same mine. Among the possible causes of such variation are differences in the proportions of the kinds of plants that formed the coal, removal and deposition of mineral matter by solutions, and wind-blown dust. Hence, in the absence of definite evidence of sediment contributed by water, such as black shale or mud partings, it is thought that, as far as the bearing on the conditions of accumulation of the vegetable matter is concerned, not much significance can be attached to the variation in the amount of ash in a coal bed of a small percentage above or below the original amount that may have come from the plants that formed the coal.

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[1] J. J. Stevenson, "The Formation of Coal Beds," *Proc. Am. Phil. Soc.*, LII (1913), 107.

The analyses given on p. 761 show that the mineral charcoal contains a smaller percentage of volatile matter and a larger percentage of fixed carbon than the average coal of the same bed. The proximate analyses (Table II) of the bright and dull laminae of the bituminous coal bed, cited by Pringle,[1] indicates that the dull laminae are similar in composition to mineral charcoal, as regards the smaller percentage of volatile matter, and the larger percentage of fixed carbon compared with the bright or the average coal.

TABLE II

	Water	Volatile Matter	Fixed Carbon	Ash
Dull laminae.	1.68	14.71	77.17	6.44
Bright laminae.	1.75	31.63	63.96	2.66

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[1] John Pringle, *Trans. Edin. Geol. Soc.*, X, Pt. 1 (1912), 33.

Lesquereux[1] described the changes that occur in the vegetable matter at the surface of swamps during dry periods as follows:

> Wherever the growth of peat in submerged bogs is checked by dryness or other causes the upper surface of the peat becomes crusted, hardened, and transformed into a thin coating quite impervious to the entrance of any kind of foreign matter, and it is upon this hard upper crust that the boggy humus forms, or, whenever the land becomes resubmerged, a new peat vegetation begins. In such cases such a crust remains as a parting between two layers of peat.

Von Gumbel in 1883 suggested: "It is very probable that in occasional drying of the swamp, followed by renewal of flooding, lies the explanation of the alternating bright and dull coal bands."

In discussing the process of putrefaction of vegetable matter of coal as described by Renault, David White[2] says that if uninterrupted the process of putrefaction goes on until all the softer tissues are disintegrated and decomposed, leaving only the most indestructible parts, immersed in a dark subgelatinous, plastic, or liquid mass, the fundamental matter. This fundamental matter not only envelops the undestroyed woody matter, but it infiltrates the surviving tissues to a greater or less extent. Where the impregnation is complete, we find dense, glossy, and shining coal. In many instances the impregnation has been imperfect, and sometimes intergrades to a charcoal or "mother of coal."

It is thought by the writer that the oft-repeated lowering, probably of only a very few inches, of the water level in the shallow swamps, and the consequent exposure of successive levels of the vegetable matter to the air, is the only adequate explanation that accounts for the extensive bedding planes practically free from clay sediments, the general distribution and alternation of the bright and dull laminae, and the large amount of mineral charcoal in the latter, as they occur in the coal beds of Illinois, the bright laminae resulting from putrefaction entirely under water, and the dull laminae and mineral charcoal resulting from partial atmospheric decay previous to the more complete subaqueous putrefaction.

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[1] L. Lesquereux, *Second Geological Survey of Pennsylvania, Ann. Rept. for 1885*, p. 118.

[2] David White, "Some Problems in the Formation of Coal," *Econ. Geol.*, III (1908), 303.

According to this view, the dull laminae and mineral charcoal partings of the coal beds are the records of repeated interruptions of accumulation, during which the surface of the vegetable material in the swamp was above water and exposed to atmospheric decay, resulting in the destruction of the softer parts of the plant tissues, leaving them in an indurated and more or less skeletonized and fibrous condition. On resubmergence these residual portions of the vegetable materials were not so readily impregnated with the fundamental matter of the bog as were those parts of the mass that had not suffered partial atmospheric decay, and hence are of dull appearance. Such periods of arrested accumulation of the plant material, due to the exposure of the surface of the vegetable matter of the bog, would be favorable for the accumulation on such a surface of a relatively larger proportion of spores than would be mingled with the vegetable mass during periods of submergence and of normal vegetable growth in the bog, and the resistant nature of the spore cases would permit their better preservation than the ordinary plant tissues during such times of exposure. These conditions would explain the greater abundance of spores in the dull than in the bright laminae of the coal beds. The variation in thickness of the dull laminae would be due to the unevenness of the surface of the exposed vegetable matter in the bog. The relatively smaller percentage of volatile matter and larger percentage of fixed carbon in the dull laminae and mineral charcoal would be explained in part by the fact that, during the times when the surface of the vegetable mass was above water and exposed to atmospheric decay, the volatile products of decomposition escaped into the air, and in part because the dull laminae were not subsequently infiltrated with the hydrocarbons of the fundamental matter to the same extent as the bright laminae.

The foregoing interpretation of the structural features of the coal beds leads to the following very definite conclusions:

1. That the beginning of vegetable accumulation of the coal beds was in a very shallow swamp.

2. That the swamp deepened so slowly, either by subsidence of the area or from the gradual building-up of the border or outlet by sedimentation, or both, that the plants were able to adjust them-

selves to the changes, and the accumulation of vegetable matter in a general way kept pace with the increasing depth.

3. That throughout the entire period of accumulation of the coal beds the water of the swamp was so shallow that during the oft-recurring cycles of drought successive levels of the vegetable mass were temporarily exposed and so modified by partial atmospheric decay as to result in the formation of the dull laminae with their mineral charcoal.

4. That the time involved in the accumulation of the vegetable material of a coal bed was the time necessary for the growth of the plants plus the time recorded in the interruptions of accumulation indicated by the dull laminae and charcoal partings of the coal, which would very greatly increase the usual estimate of time required.